THE PREVENTION OF CYCLOPROPANE–OXYGEN EXPLOSIONS BY DILUTION WITH HELIUM *

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Introduction

The results presented were obtained through a cooperative effort of the Bureau of Mines, Department of the Interior, and a committee comprising representatives of the Department of Industrial Hygiene, School of Medicine, University of Pittsburgh, the St. Francis Hospital, the American Society of Heating and Ventilating Engineers, and various hospitals and industries in the Pittsburgh district.

Cyclopropane has many desirable characteristics as an anesthetic agent, and increased consumption of this gas may be expected provided the explosion hazard now attending its use can be minimized or eliminated. The authors feel that mixtures containing 20 per cent. cyclopropane and 80 per cent. oxygen, now commonly employed, are so violently explosive that their use should be discouraged.

Prevention of Explosions by Oxygen Control

One of the most satisfactory means of eliminating the explosion hazard of combustible gaseous mixtures lies in the control of their oxygen content. When the oxygen content of such mixtures is reduced by the addition of inert gases the range of explosibility is narrowed. With continued dilution with inert gases an oxygen concentration finally is reached at which the mixtures are no longer explosive or inflammable (1, 2, 3, 4, 5, 6, 7, 8). Clinical experiments at various hospitals in Pittsburgh have shown that the explosive violence of such mixtures can be reduced and even eliminated by proper dilution of cyclopropane-oxygen with inert gases.

Of the three inert gases carbon dioxide, nitrogen and helium, whose respective flame quenching properties have been investigated in connection with cyclopropane-oxygen mixtures (9), it has been shown that volume for volume, carbon dioxide, owing to its higher molecular heat capacity, is the most efficient for the elimination of explosion hazards. However, this gas cannot be used to dilute anesthetic mixtures because

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the large quantities required exert a marked physiological effect upon patients.

Of the two remaining inert gases, nitrogen and helium, the latter appears the more promising. Helium is a light gas, about one-seventh as heavy as nitrogen, and therefore can be breathed with less effort than a mixture containing a similar percentage of nitrogen. Its flame quenching qualities are about the same as those of nitrogen (9). Coward, Cooper and Jacobs (10) have found that mixtures containing helium are more difficult to ignite by electrical discharges than mixtures containing similar percentages of other inert gases. It has also been observed in our investigation that mixtures of cyclopropane, oxygen and helium, in which the helium content equals 50 per cent. or more, are much more difficult to ignite by the usual sparking devices employed in apparatus for gas analysis.

The cyclopropane used in these tests was obtained from the Ohio Chemical & Manufacturing Company, Cleveland, Ohio and was further purified to agree closely with the calculated ratio for pure cyclopropane. The helium was obtained in cylinders from the Bureau of Mines Helium Production Plant at Amarillo, Texas and showed a purity of 98.2 per cent.; the remaining 1.8 per cent. was largely nitrogen. The gas contained less than 0.1 per cent. methane and other hydrocarbons. The oxygen, obtained in cylinders, was shown to contain less than 1 per cent. nitrogen. The tests were conducted in an explosion-tube apparatus that afforded the widest limits of inflammability, and which was employed in earlier investigations dealing with the extinction of flames.

The limits of inflammability of cyclopropane in pure oxygen were determined first. A lower limit of 2.48 and an upper limit of 60.0 per cent. by volume were obtained; that is, any mixture of cyclopropane in oxygen ranging from 2.48 to 60.0 per cent. is inflammable. Increasing amounts of helium were then added to the cyclopropane-oxygen mixtures and the limits of inflammability determined. The results are shown graphically in Figure 1.

It will be seen that dilution with helium has only a minor effect on the lower limit of inflammability. The results indicate a decrease from 2.48 per cent. lower limit in pure oxygen to a minimum of 2.15 per cent. when the mixture contained about 75 per cent. of helium. The upper limit is affected markedly by the amount of helium present.

From the standpoint of anesthesia, mixtures containing 2.15 per cent. of cyclopropane are too dilute to be of value. However, a series of mixtures may be used that are above the upper limit of inflammability and therefore noninflammable until air or oxygen is added to the same. All mixtures falling in the area to the right of the curve CE and containing from 3 to 60 per cent. of cyclopropane may be used safely by careful control of the cyclopropane and oxygen content, since there is a direct relationship between the percentages of the two gases present that must be maintained if explosions are to be prevented. To control the atmosphere in the anesthetic apparatus so that the composition at all times is outside the inflammable area, the graph in Figure 1 is used. The explosive hazards involved can be determined at a glance provided the composition of the mixture is known.

If a mixture, such as that represented by *J* is decided upon, the following procedure of administration may be followed. At the beginning, employing a closed recirculating type anesthetic machine, both the free space in the machine and the patient's lungs will consist largely of

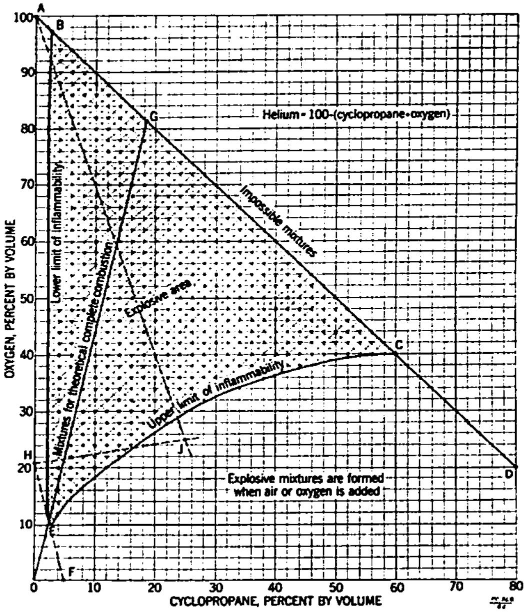

Fig. 1. Explosibility of cyclopropane, oxygen and helium mixtures.

normal air, having approximately 20.9 per cent. oxygen and no cyclopropane present. This condition is represented at the point *H*. As the 25–25–50 mixture of cyclopropane-oxygen-helium is administered the composition of the atmosphere in the apparatus will shift along the broken line *H* to *J* and pass through the range of inflammable mixtures shown. However, this phase can be carried out under conditions that are outside the inflammable range if at the beginning the oxygen content is lowered about 10 per cent. by increasing the supply of helium, so that the composition of the mixture passes from *H* to *E* and then to *J*.

The mixture represented by *J* can be administered to the patient throughout the anesthesia without danger of an explosion (additional oxygen must be administered to meet the basal requirements of the patient). Should leakage occur a fire may break out at the point of leakage if the gas mixture is ignited because, as shown in the graph, the addition of air to the mixture represented by *J* will shift the composition to the left along the line *JH* bringing it within the area of inflammability.

From the explosion standpoint, the dangerous practice of sweeping out the patient's lungs with pure oxygen at the conclusion of the anesthesia becomes apparent on inspection of the graph. The composition and explosibility of a mixture under such a procedure are depicted by the broken line *JA*. Starting with the mixture *J*, addition of pure oxygen rapidly brings it within the explosive range and maintains it there until the cyclopropane has been diluted to below 2.4 per cent.

OXYGEN REQUIREMENTS AND ADMINISTRATIVE TECHNICS

A series of tests was next conducted upon humans to determine the oxygen requirements and desirable technics for administering oxygen-helium-cyclopropane mixtures.

It was found that the average individual's oxygen requirement was 250 cc. to 400 cc. per minute, a figure somewhat above the values usually cited.

The desirable rate of increase of oxygen is shown in which the oxygen concentration slowly increases from about 11 to 12 per cent. at the beginning and reaches 20 to 25 per cent. at the end of one hour period. Inspection of the area of inflammability of cyclopropane-oxygen-helium mixtures in the graph shows that higher concentrations of oxygen may be used as the cyclopropane is increased, but a definite relationship must be maintained if inflammable atmospheres are to be avoided. The following table gives the oxygen concentrations that should not be exceeded for different percentages of cyclopropane:

Cyclopropane (per cent.)	Oxygen Concentration Should Not Exceed (per cent.)
4	12
6	15
8	17
10	18
12	20
14	22
18	25
25	30

PRESENT TECHNIC FOR ADMINISTRATION OF NON-INFLAMMABLE CYCLOPROPANE–OXYGEN–HELIUM MIXTURES

The following technic has been devised for the administering of non-inflammable cyclopropane-oxygen-helium mixtures: *

* The technic recommended for administering of noninflammable cyclopropane-oxygen-helium mixtures is for the average adult patient. The dosage must be governed by the pa-

The gas machine must be equipped with a carbon dioxide absorber and a helium attachment having calibrated flow-meters covering a range from 100 to 5000 cc. per minute.

Adequate and proper premedication is essential for satisfactory anesthesia.

(1) Purge the gas machine for two minutes with 500 cc. of oxygen and 3 liters of helium in order to eliminate any residual gas from a previous anesthetic.

(2) Empty the bag.

(3) Set the needle valves so that the gases will flow in the following proportions:

Oxygen	500 cc. per minute.
Cyclopropane	500 cc. per minute.
Helium	1000 cc. per minute.

(4) Place the mask securely on the patient's face. Administer the above proportion for three minutes and then change to the following:

Oxygen	500 cc. per minute.
Cyclopropane	500 cc. per minute.
Helium	150 cc. per minute.

(5) Continue the above mixture until the patient enters the desired plane of anesthesia. Then administer the oxygen according to the patient's metabolic requirements. This usually requires from 300 cc. to 450 cc. per minute. Use only sufficient oxygen to satisfy basal requirements.

The cyclopropane is administered *continuously* at rates varying from 50 cc. to 200 cc., depending upon the plane of anesthesia desired.

If the bag becomes too greatly distended, reduce the helium to 100 cc. It may, however, be necessary to release the pressure at frequent intervals at the exhaling valve.

Note.—The carbon dioxide filter should be turned on at the beginning of the administration of the anesthetic or shortly thereafter, due to the accumulation of carbon dioxide that usually occurs during anesthesia. If there are any signs of cyanosis or change in the rhythm of the pulse, oxygen should be increased to correct these conditions.

At the completion of the anesthesia *all* the gases should be turned off, the face mask removed and the machine pushed away from the patient. DO NOT FLUSH THE PATIENT WITH OXYGEN. THIS IS VERY DANGEROUS BECAUSE IT WILL IMMEDIATELY THROW THE MIXTURE INTO THE EXPLOSIVE RANGE.

In the event of leakage about the face mask or any other part of the

tient's metabolic requirements, type and degree of premedication. Furthermore, we have found it necessary to vary our technic when using different types of apparatus because the calibration of gas machines varies. However, this last procedure may soon be corrected by the manufacturers. Therefore, in using cyclopropane-oxygen-helium mixtures a close observation must be kept of the patient and the proper adjustment of the various gases made to maintain the desired plane of anesthesia.

anesthetic apparatus the bag may be refilled by using the technic described in the induction period.

The above conclusions, from tests made with helium-oxygen mixtures, are intended to serve as a guide to those who may be interested in testing the general method of obtaining noninflammable mixtures through the control of their oxygen content by the addition of helium. The tests conducted indicate certain difficulties that may be encountered, especially because of the variable oxygen requirements of different patients, and the rapid change in the mixture composition should a leak develop and the mixture be lost from the apparatus.

At the present state of development the method requires rather close control of the oxygen concentration, and it has been found difficult in some cases to maintain the desired concentration because, as yet, there is no simple and quick method of determining the amount of oxygen present in the apparatus. While it was found that an abnormally low oxygen concentration caused a rapid rise in pulse rate, this may not always be true when cyclopropane is present.

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THE SECTION ON ANESTHESIA OF THE CONNECTICUT STATE MEDICAL SOCIETY will meet on the afternoon of May 21, 1941, in Bridgeport, Conn. The following speakers will be heard:

1. Wesley Bourne, M.D., Royal Victoria Hospital, Montreal Canada, on "Breathing in Anesthesia."
2. Henry K. Beecher, M.D., Massachusetts General Hospital, Boston, Mass. (Title to be announced.)
3. Jacob H. Fine, M.D., Beverly Hospital, Beverly, Mass. (Title to be announced.)